Amelioration of soil acidity in Ferralsols of Central Uganda

Abstract

A field study was conducted on farmers' fields in Central Uganda to determine the effects of calcium carbonate and corncob biochar on soil acidity ~~was conducted on farmers' fields in Central Uganda~~. Prior to the field design, soils were sampled from Mpigi, Mubende and Wakiso districts for greenhouse incubation study. Hence, 2 kg of soil was weighed, placed in a plastic container and thoroughly mixed with 0, 1, 3 and 5 g equivalent to 0, 1, 3 and 5 tons/ha calcium carbonate and corncob biochar. Soil in each plastic container was moistened with 500 ml of water to bring it to about field capacity and pH determination done for a period of three (3) months. The different rates of lime used in the greenhouse were used to calculate the rates i.e., 120, 360 and 600 g applied in the fields. The rates of $CaCO_3$ and corncob biochar (0, 120, 360 and 600 g) were applied as the sub plot while the soybean varieties (improved and local) were applied as the main plot. The analysis of variance (ANOVA) showed that $CaCO_3$ significantly influence ($p<0.001$) soil pH in all the study locations with Mpigi recording the highest soil pH (6.7) followed by Mubende (pH 6.6). Besides, rates of $CaCO_3$ and corncob biochar significantly ($p<0.001$) influenced soybean grain yield compared to 0 kg ha^{-1} of lime. Corncob biochar, a locally available soil amendment was observed to have had significant effect ($p<0.001$) on soil pH with 600 g recording a pH of 6.3 in Mpigi and Wakiso districts respectively. Besides, application of 600 g of $CaCO_3$ recorded the highest (7137.5 kg ha^{-1}) soybean grain yield in Wakiso among the improved soybean genotype compared to plots treated with 120 and 360 g $CaCO_3$. It was also observed that 600 g biochar recorded 5637.5 kg ha^{-1} grain yield in Mpigi suggesting the potential benefit of corncob biochar on Acid Ferralsols for improve crop production and productivity.

Key words: Soil acidity, Ferralsols, $CaCO_3$, corncob biochar, soybean grain yield

Introduction

Ferralsols in Central Uganda have been established to be strongly to very strongly acidic with a pH ranging from 4.7 to 5.0. Besides, the soils have low exchangeable cation and low available N, P and K coupled with low organic matter and high Al^{3+} ion concentration (Add reference). The soils are becoming unfavorable for agricultural production thus requiring remediation strategy to reverse the threat. The soils are mostly found in the humid and sub-humid tropics, where temperatures and precipitation are high (FAO and ITPS, 2015). In Uganda, the soils are the most dominant of the 22 soil types with 25 % spatial coverage (Bamutaze, 2015). The extent and management of these soils are inadequate among smallholder farmers in Central Uganda due to the high cost of inorganic lime. Increasing crop production and productivity on these soils will require the addition of soil amendments such as calcium carbonate, biochar etc., as soil fertility has shown to be a manageable practice, and its management is important for optimizing available plant nutrient to achieve crop yield.

The deteriorating soil fertility in Central Uganda is largely contributing towards reduce agricultural production and food security among smallholder farmers where majority of the population relies on subsistence farming as a source of livelihood. Inorganic fertilizer used as a significant soil nutrient replenishment is unsustainable, causing adverse environmental effects, including soil acidity (Kabasiita *et al.*, 2022). Generally, soil acidity elevates aluminum (Al^{3+}) concentration within the soil solution to a level toxic to plants, limits the availability of essential plant nutrients, and restricts crop performance **(**Alvarez *et al.,* 2020). Restoring soil pH to optimal range for agriculture production can have significant impact on yields. Henceforward, liming is the most common management practice used to neutralize and overcome problems associated with soil acidification (Fekadu *et al.,* 2019). Dai *et al.*, (2017) reported significant increase in soil pH when different rates of biochar were added. The ability of biochar particles to absorb the H^{+} ions as well as decarboxylation processes are probably the main factors in soil acidity neutralization (Wang and Liang, 2013).

Comment [H1]: Give some details about biochar

As soils become more acidic, plants that are intolerant to acidic conditions would be negatively affected leading to productivity decline (Fekadu *et al.,* 2019). Achalu *et al.,* (2012) conducted a greenhouse-based incubation of acidic soils treated with lime and the result showed that the application of 10 t ha^{-1} calcium carbonate incubated for 90 days significantly reduced the strength of soil acidity levels and severity of exchangeable acidity and Al^{3+} saturation in the soils. The current soil fertility management practices that smallholder farmers are using across Central Uganda namely: recycling of crop residues, addition of cow manure, short fallow and biomass transfer appeared to be inadequate to counter the effects of soil acidity. Besides, many smallholder farmers in Central Uganda are depended on these soils to sustain themselves. The lack of awareness among farmers and the enormous benefits of agricultural lime i.e., $CaCO_3$ and biochar would have on soil acidity (soil pH) and plant nutrient output among smallholder farmers in the study area is lacking. The study presumed that different rates of $CaCO_3$ and corncob biochar will increase the soil pH of acid Ferralsols, and improve on soybeans grain yield. Additionally, corncob biochar, a locally available material on farmers' fields in Central Uganda will help resource limited farmers in addressing the problem of soil acidity while saving on the cost of purchasing inorganic lime ($CaCO_3$). The purpose of this study therefore, was to understand the current pH status of Ferralsols in Central Uganda as a way of providing further soil fertility recommendation strategies to existing ones so as to enhance the production of soybean and other arable crops on smallholder farms in the region.

Comment [H2]: Need refinement.

Materials and Methods

Soil Sampling and Preparation

Three (3) districts namely: Mpigi, Mubende, and Wakiso in Central Uganda were randomly selected. Thereafter, bulk samples were collected and transported to the Faculty of Agriculture, Uganda Martyrs University for greenhouse incubation study. Besides, known quantity of soil at a depth of 0-20cm was sampled from farmers' fields with the use of an auger and thoroughly mixed to form composite sample. The samples were placed in a plastic bag, labeled, and transported to "Les Rams Consultant, Water Quality, Soil and Plant

Analysis Laboratory" situated in Kampala, Uganda, Apollo Kaggwa Road, Bwaise. The samples were air dried ground to pass through ~~a~~ 2 mm sieve for the initial pH analysis.

Soil Chemical Analyses

Soil pH was determined in 1:2.5 soil water ratio using a glass electrode attached to a digital pH meter as described by Okalebo *et al*. (2002).

Greenhouse Incubation Study

Air-dried soil was ground to pass through ~~a~~ 2 mm sieve. After that, 2 kg of soil was weighed and placed in a plastic container. Different rates, i.e., 0, 1, 3, and 5 g equivalent to 0, 1, 3 and 5 tons/ha of calcium carbonate and corncob biochar were added to each plastic container and moistened with 500 ml of distilled water to bring it to about field capacity thus allowing the reactions to take placed overtime. Soil in each plastic container was moistened, monitored and pH determination done biweekly for a period of three (3) months as described by Watson and Brown (1998).

Average yield (kg/ha)

Yield in kg/ha was calculated by multiplying yield per plant by 10 000 m^2 and dividing the sum by 1000 kg. This resulted to yield in kg/ha.

Experimental Design and Treatments

The field experiments were setup on farmers' fields in Mpigi, Mubende, and Wakiso districts to assess the different lime rates on soil pH and soybean grain yield. The experimental design was a Complete Randomized Design (CRD) with two varieties of soybeans (Improved and local). The soybean varieties were ~~applied~~ used as the main plot while calcium carbonate and biochar rates were applied as the subplot. The treatments were replicated four (4) times, and the crops spaced at 0.5 x 0.2 m for inter-row and intra-row. Subplot size was 2 x 2 m while main plot size was 8 x 2 m. Subplots were separated by 0.5 m pathways while main plots were separated by 1 m. The study had sixteen (16) main plots and sixty-four (64) subplots. Each subplot had four rows with 5 plants per row. The length of the field was 41 m and width 11 m. The total area used for the experiment was 451 m^2.

Data collected

For the ~~Greenhouse~~ greenhouse study, 10 g of soil was collected from each plastic container for soil pH determination. For the field experiments, soil samples were collected before planting and at 50% flowering and the pH determined. For soybeans, data was collected on grain yield.

Data ~~Analysis~~analysis

All data collected were subjected to analysis of variance (ANOVA) using GENSTAT 16th edition and declared significant at $p<0.05$ using the statistical model as described by Gomez and Gomez (1984). Mean separation was done using the Duncan's Multiple Range Test (DMRT) and conclusions made at $p<0.05$ levels of significance.

Results and Discussions

Main effect of lime rates and incubation period on soil pH optimization

The analysis of variance (ANOVA) showed that the main factors i.e., rates of $CaCO_3$ and corncob biochar application showed significant effect ($P<0.001$) on soil pH followed by the study locations ($P<0.001$). Besides, interaction effect and incubation period also showed significant effect ($P<0.001$) when different rates of $CaCO_3$ and corncob biochar were applied (Table 1). The study location and treatment application also observed significant effects ($P<0.001$) on soil pH. The study observed a consistent increased in the initial soil pH (4.7 and 5.0) when different rates of $CaCO_3$ and corncob biochar were applied (Table 2) thus suggesting an improvement in the soil pH. Application of 5 g of $CaCO_3$ increased the soil pH to the targeted soil pH with Mubende recording a pH of 6.7 in week 8 followed by Mpigi and Wakiso in week 12 (Table 2). Our findings conformed to those of Fekadu et al. (2019) who reported significant increase in the initial soil pH i.e., 3.9 to near optimal pH of

6.0 and 6.5 when rates of calcium carbonate were applied. With the application of 3 g of $CaCO_3$, the study observed the pH changing from their initial states to pH 5.8, 6.0, 6.1, 6.2, 6.3, 6.4 and 6.6 across the different study locations with the highest recorded in Wakiso (Table 2) thus suggesting the effectiveness of $CaCO_3$ in Ferralsols.

The application of 5 g of corncob biochar observed an increase in the soil pH from 4.7 to 5.6 in week 4 to 5.7 in week 8 and 5.9 in week 12 (Table 2). With the addition of 1 and 3 g of corncob biochar, we observed the pH progressively changing as shown in Table 2. The study however noted uncleared pH trends after the application of different $CaCO_3$ and biochar. The uncleared trends showed that soils in the study area reacted differently to liming. Fekadu *et al*. (2019) reported no clear trends on soil pH when different rates of lime were applied to acid soil and allowed to incubate for four weeks. Notwithstanding, the recorded soil pH in the study i.e., 5.5, 5.8, 5.9, 6.0, 6.1, 6.4, 6.5, etc., clearly indicates an ideal soil pH for agricultural activities. Similarly, FAO (2012), reported soil pH 6.5 to 7.5~~.~~ as ideal for agricultural production.

Interaction effect of lime rates and incubation period on soil pH

The weekly pH recorded for rates of biochar observed the pH increasing as the weeks passed on by. In week 4, 8 and 12 the pH had increased from 4.7 in Mpigi to 5.2, 5.3 and 5.4 when 1g of biochar was applied. Application of 1 g of biochar in week 4, 8 and 12 also observed the pH increasing from 5.0 to 5.4, 5.6 and 5.8 in Mubende district (Table 2). Similarly, in Wakiso district, the initial soil pH was observed to have increased from 5.0 to 5.6, 5.8 and 6.0 suggesting 2 % increase from 5.6 to 6.0 when 1 g of biochar was applied. During weeks 8 and 12, the study observed that 3 and 5 g of biochar had increased the soil pH from its deplorable states to a near neutral levels at which plant nutrients become readily available for uptake. At 4 weeks interval, application of 1, 3 and 5 g of $CaCO_3$ observed the pH gradually increasing from Mpigi to Mubende and Wakiso districts respectively (Table 2). Application of 1 g of $CaCO_3$, we observed the pH in the range of 5.2 in week 4 to 5.8 in week 12 in Wakiso, 5.7 to 6.0 in Mubende, and 5.9 to 6.2 in Wakiso districts respectively (~~table~~ Table 2). As the rates of application increased to 3 and 5 g of $CaCO_3$, the soil pH was observed to be in the range of 5.8 to 6.7 in the different study areas (Table 2).

Our findings are in agreement to those of Nyamaizi et al. (2021) who reported the application of several rates of $CaCO_3$ to increase the soil pH values from 4.1, 4.8, and 5.5 to 6 and from 5.8 to 6.5 to enhance phosphorus availability in acid soil.

Effect of lime rates on soil pH in Ferralsols of Central Uganda

Significant difference ($p<0.001$) was observed on soil pH in the different study areas with Mubende recoding the highest soil pH (6.7) followed by Mubende (pH 6.6) and Wakiso (pH 6.3) among the improved variety. Application of 600 g of $CaCO_{3,}$ observed an optimum increased in the initial soil pH from 4.4 in Mpigi to 6.7. Mubende district also observed a change in the initial soil pH (4.8) to 6.6 when 600 g of $CaCO_3$ was applied. In agreement to our findings, Warner *et al.* (2023) revealed that treatments that received the highest dose of lime resulted in the highest value of soil pH (6.7). Additionally, application of 600 g of $CaCO_3$ and corncob biochar observed the pH to be increasing in Wakiso district (figure 1). The study however observed the highest pH amongst the improved soybean variety in all the study areas (figure 1). Application of 120 g of $CaCO_3$ also observed a pH of 5.8 in Mpigi followed by pH 5.6 in Mubende with Wakiso recording a soil pH of 5.9 among the improved genotype.

Application of 120 g of biochar observed a gradual increase in the soil pH among the two soybean genotypes used in the study with Mpigi recording a pH of 5.3 among the improved variety while pH 5.2 was recorded among the local variety (figure 1). Furthermore, 120 g of biochar also recorded a pH of 5.4 under the improved variety in Mubende followed by pH 5.5 under local variety. Similarly, a field trial conducted by Bass *et al.* (2016), observed the application of biochar to have significantly increased the soil pH only in the first half of the trial, however, at the trial completion, differences among treatments were not significant. Similarly, studies conducted by Frimpong (2018) observed significant increased ($p<0.001$) on soil pH when different rates of biochar were applied. 360 g of $CaCO_3$ and biochar observed a gradual increase in the initial soil pH in all the study area among the two soybean genotypes (figure 1). Likewise, application of 360 g of $CaCO_3$ recorded the highest soil pH under the improved variety in Mpigi while 360 g of biochar observed slight increase in the soil pH in Mubende under the local variety followed by Wakiso (figure 1). The findings from the study showed that an increased in treatment application of $CaCO_3$ and corncob biochar observed an increased in soil pH (figure 1).

Effects of liming on soybean grain yield in Acid Ferralsols

When soybean grain yield was evaluated, we found that treatment application showed significant difference ($p<0.001$) figure 2. When interaction of treatment and soybean genotypes were assessed, the study also found significant difference ($p<0.001$) on grain yield among the selected soybean genotypes. Hence, application of 600 g of $CaCO_3$ recorded the highest (7137.5 kg ha^{-1}) grain yield in Wakiso among the improved soybean genotype followed by 6600 kg ha^{-1}grain yield in Mubende district respectively. The study also observed minimum increased in soybean grain yield among improved and local soybean genotypes across the different study locations compared to untreated plots. The study found that plots treated with 600 g biochar recorded significantly higher (5637.5 kg ha^{-1}) grain yield in Mpigi compared to plots treated with 120 and 360 g biochar. Notably, the study recorded increased soybean grain yield with extra application of either $CaCO_3$ and biochar in all the study locations suggesting the impact the two soil amendments have on the amelioration of acid soil for improve crop production. Our findings are in agreement with those of Bedassa et al. (2022) who reported maximum grain yield of 1943.93 kg ha^{-1} under lime treated soil as opposed to 510.49 kg ha^{-1} under lime untreated acid soil. In the same way, Ameyu *et al*. (2022) showed that 'no lime' gave the lowest grain yield of 1269 kg ha^{-1} compared to 6268.9 kg ha^{-1} of soybean grain yield in limed acid soils. Our findings conformed to those of Yooyen *et al.* (2015) who reported that biochar treated soils elevated levels of soil pH, and showed statistically significant difference ($p<0.05$) on soybean grain yield compared to the control plot (0 kg ha^{-1}).

Conclusion

At the end of the greenhouse incubation and field study, soil pH was successfully raised to the target values with the addition of $CaCO_3$ and corncob biochar. We observed decreasing trends of soil pH from the initial to near neutral at which plants thrived as observed from the accumulation of soybean grain yield in the study. Because extra amount of $CaCO_3$ and corncob biochar were added, the final soil pH reached 6.7 in the selected districts representing Central Uganda. The results highlight the potential effects $CaCO_3$ has on soil acidity as opposed to corncob biochar.

These relationships indicate that the decreasing trends of soil pH could be due to the association of Ca^{2+} acting as a sink for the suspension of Al^{3+} and H^+ on the soil exchange sites. The role of $CaCO_3$ and corncob biochar certainly deserve combine investigation when studying liming effects in acid Ferralsols for soil pH improvement and accumulation of soybean grain yield.

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Table 1: Source of variation for the greenhouse incubation study

Source of Variation	d.f	P.H
Location	4	21.58***
Treatment	7	19.77***
Week	4	0.14^{NS}
Location x treatment	28	2.59***
Location x Week	16	0.24*
Treatment x Week	28	0.07^{NS}
Location x Treatment x Week	112	0.10^{NS}
Residual	600	0.12
SE		0.3466
LSD		0.4813
CV (%)		6.4

***Significant at 0.1%, **Significant at 1%, *Significant at 5%, NS=Not Significant, df=degrees of freedom

Table 2: Weekly soil pH levels at different incubation periods

District	Treatment (g)		Week 4	Week 8	Week 12
Mpigi	$CaC0_3$	0	4.7c	4.7c	4.7c
		1	5.2b	5.5b	5.8b
		3	6.2a	6.3a	6.4a
		5	6.4a	6.5a	6.7a
	Biochar	0	4.7c	4.7c	4.7c
		1	5.2b	5.3b	5.4b
		3	5.4b	5.5b	5.7b
		5	5.6b	5.7b	5.9b
Mubende	$CaC0_3$	0	5.0b	5.0b	5.0b
		1	5.7b	5.9b	6.0a
		3	5.8b	6.1a	6.4a
		5	6.6a	6.7a	6.7a
	Biochar	0	5.0b	5.0b	5.0b
		1	5.4b	5.6b	5.8b
		3	5.5b	5.8b	6.0b

		5	5.9b	6.0a	6.2a
Wakiso	$CaCO_3$	0	5.0b	5.0b	5.0b
		1	5.9b	6.1a	6.2a
		3	6.0a	6.3a	6.6a
		5	6.3a	6.5a	6.7a
	Biochar	0	5.0b	5.0b	5.0b
		1	5.6b	5.8b	6.0a
		3	5.8b	6.1a	6.3a
		5	6.0a	6.3a	6.5a

Note: a, b and c means sharing a letter in their superscript are not significantly different at the 0.05 level. However, a and b, b and c and c and a are significantly different at 0.05 level.

Table 3: Quantity of lime applied to raise the soil pH to the expected pH

Rates of liming materials per 2 Kg weight of soil applied in the greenhouse	Amount of lime applied in the field (g/plot)	Expected pH value
Control	0	5.0
1g	120	5.5
3g	360	6.0
5g	600	6.5

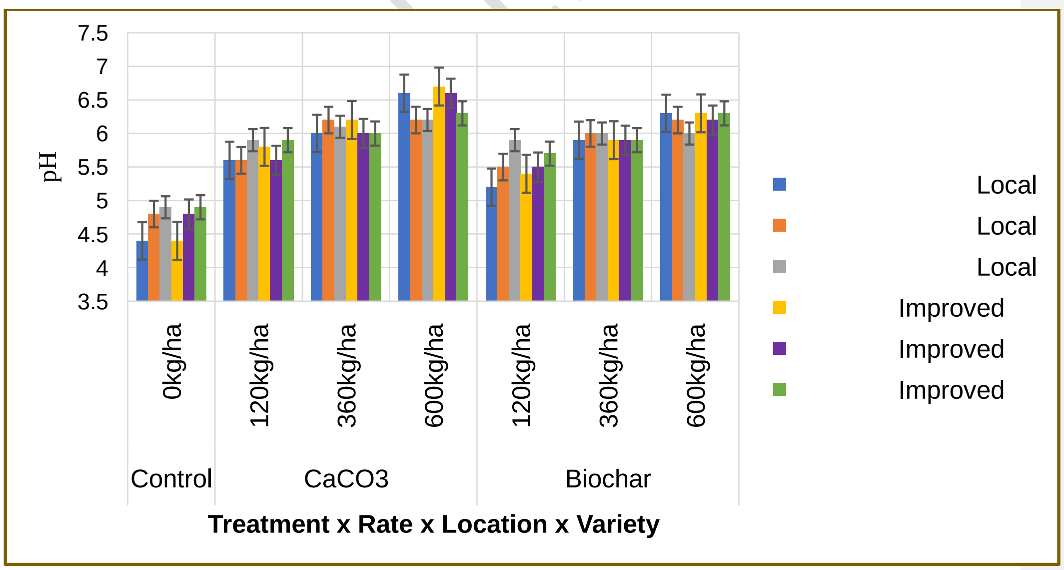

***Figure 1**: Soil pH response to liming on acid Ferralsols in Central Uganda*

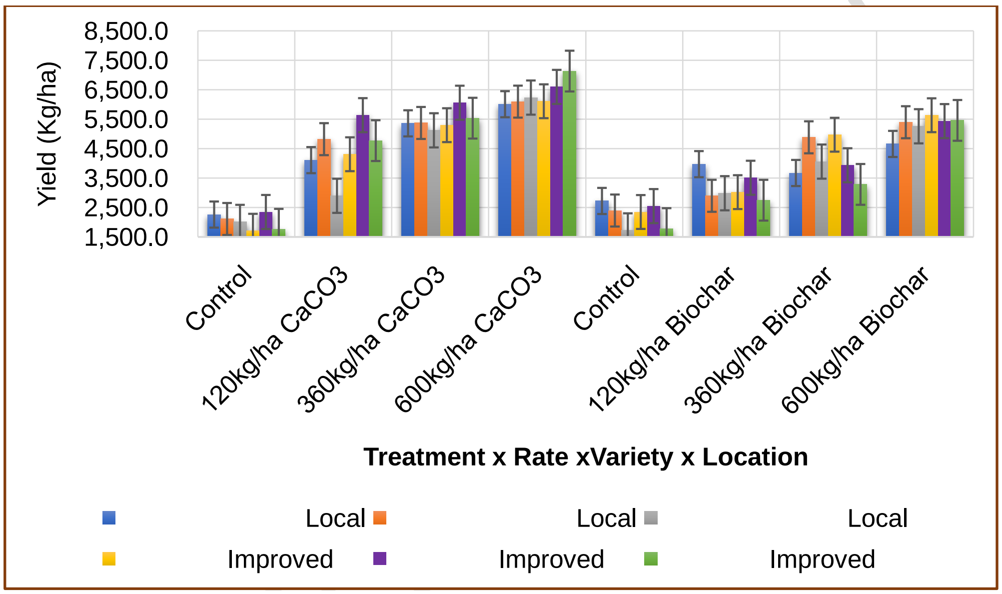

***Figure 2:** Effects of lime rates on soybean grain yield in Ferralsols of Central Uganda*